



**SYSTECH WATER RESOURCES, INC.**

*ENVIRONMENTAL ENGINEERING AND  
WATER RESOURCES SYSTEMS ANALYSIS*

**Calibration of the Link-Node Model  
for Application to Understanding  
Causes of Low Dissolved Oxygen Conditions  
in the Stockton Deep Water Ship Channel**

**Report 5.1.1**

**CALIFORNIA DEPARTMENT OF FISH AND GAME  
GRANT AGREEMENT E0883006**

Prepared by

Scott Sheeder and Joel Herr

Systech Water Resources, Inc.  
1200 Mount Diablo Blvd, Suite 102  
Walnut Creek, CA 94596  
(925) 355-1780

In Cooperation with

Ecological Engineering Research Program  
School of Engineering & Computer Sciences  
University of the Pacific  
3601 Pacific Avenue  
Chambers Technology Center  
Stockton, CA 95211

December, 2013

# 1 Introduction

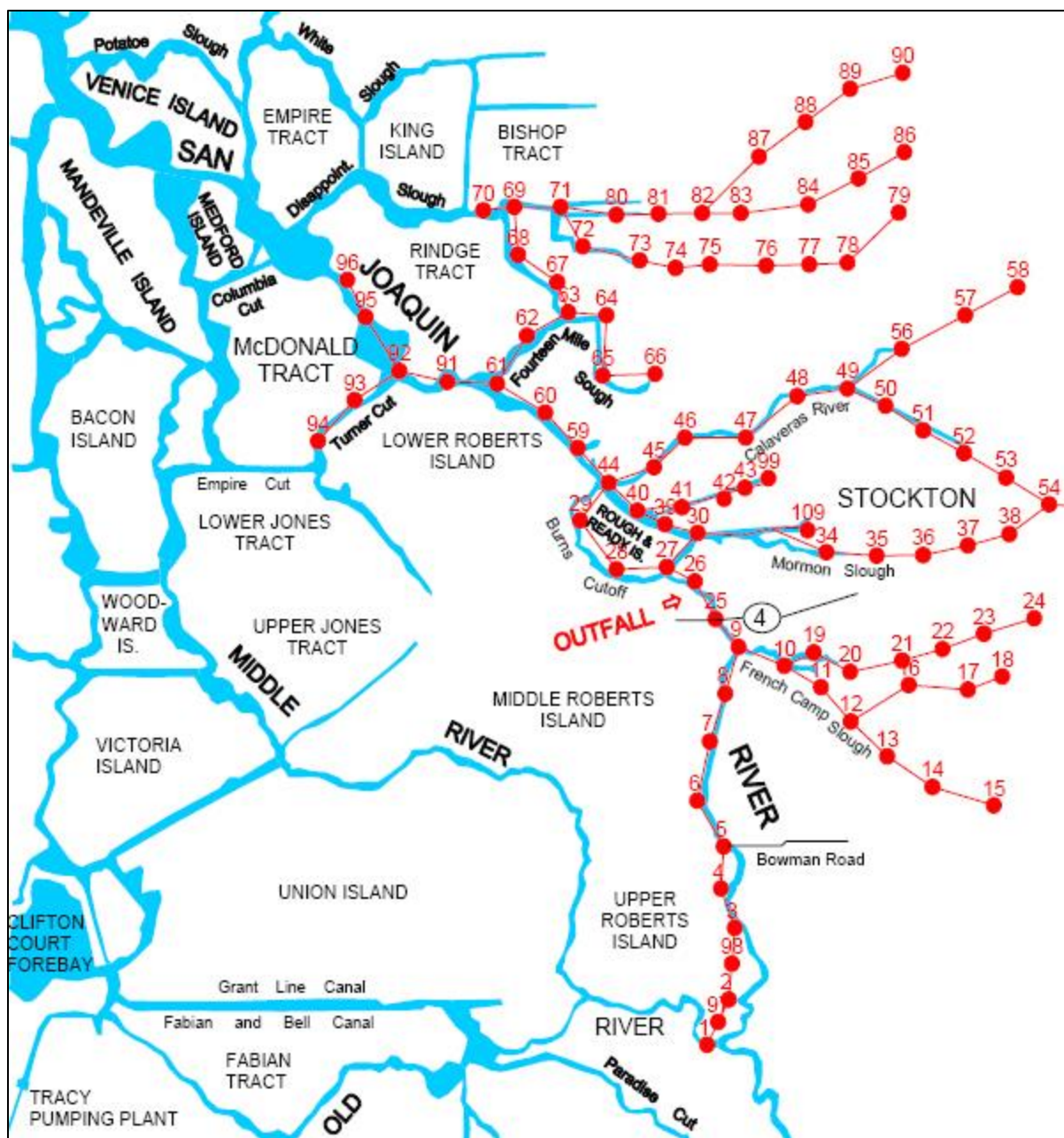
Dissolved oxygen in the Lower San Joaquin River is controlled by a large number of factors. These factors include tides at the downstream end, the stream flow at the upstream end, stream flow from tributaries on the east side of the San Joaquin River, channel depth, water temperature, and various dissolved oxygen (DO) sinks and sources including (i.e. phytoplankton, biochemical oxygen demand, and ammonia). The factors controlling DO concentration can change with time by hour, day, and season. The dynamic nature of the estuary system makes it difficult to perform statistical correlations of parameters, measured at discrete places and times. No single factor can be used to explain the observed DO change, because all factors work in concert to affect the DO in the lower San Joaquin River.

In 1993 Systech Water Resources, Inc. began development of the Link-Node model of the lower San Joaquin River (Figure 1) to evaluate the causes of dissolved oxygen depletion in the vicinity of the Stockton Deep Water Ship Channel (Schanz and Chen 1993) (Chen and Tsai 1997). The model was adapted and modified from the link-node model of Chen and Orlob (1975), which employed the basic hydrodynamic formulations developed by Feigner and Harris (1970). The water quality formulations to track the mass and concentration of multiple constituents interacting within each model node are based on work conducted by Chen (1970).

Many improvements in the model have been made since the original formulation. In 2000, a grant from CALFED provided funding for two peer reviews (USEPA and a CALFED internal review) of the model formulation and modification of the model formulation based on the peer review comments. The grant enabled the compilation of a dataset including observed water quality at locations throughout the lower San Joaquin River, observed hydrology in the San Joaquin River at Vernalis, observed tidal elevation data, and point source data from the Stockton Regional Wastewater Control Facility. Additional water quality parameters were added to the model including phytoplankton and detritus. Flexibility was added to the simulation code that allowed the user to specify the model timestep.

The current project, funded by the California Department of Fish and Game, has further advanced the capabilities of the Link-Node model. All of the input datasets were expanded to allow simulations to extend from 10/1/2004 through 9/30/2012. The observed hydrology and water quality datasets were extended through 9/30/2012 to enable calibration over the same time period. The precision and accuracy of the tidal elevation datasets were greatly improved by incorporating high temporal resolution (15-minute or 1 hour) water surface elevation data collected at Turner Cut near Holt, the San Joaquin River near Venice Island and the San Joaquin River at Rough and Ready Island. Five scenarios were simulated following the model calibration.

These scenarios were selected to isolate different sources of oxygen depletion thereby determining the relative importance of each source to the DWSC dissolved oxygen deficit. In each of four scenarios, one source of oxygen consuming materials (phytoplankton, ammonia, BOD) was removed from the model inputs. The four sources include the San Joaquin River upstream of the Link-Node model boundary, the rivers and sloughs that are tributary to the Link-Node model boundary, the Stockton Regional Wastewater Control Facility, and the DWSC itself where dredging has increased residence time promoting oxygen depletion. The current project was conducted under an adaptive management framework allowing for flexibility in the tasks as the project evolved. Field data and simulation results indicate that zooplankton grazing may have a significant influence on phytoplankton populations and by extension dissolved oxygen concentrations. Therefore, numerical code describing zooplankton grazing and distribution was added to the Link-Node model. This functionality was added to the model following model calibration and simulation of the four oxygen depletion scenarios. While initial zooplankton model results are presented herein, further testing and calibration of the zooplankton routines is recommended and could be accomplished as part of a future project.



**Figure 1.** The link-node system of the San Joaquin River DO model.

## 2 Link-Node Model Calibration

Accurate and precise simulation of dissolved oxygen in the San Joaquin River Deep Water Shipping Channel is dependent upon the quality of input datasets, an accurate mathematical representation of the estuary bathymetry, and calibration of the Link-Node model parameters that affect the hydrodynamic and water quality simulation. The objective of calibration is to minimize the absolute and relative error and maximize the r-squared statistic calculated from

Link-Node simulation output and measured data. The calibration effort was focused on optimizing simulation performance for water surface elevation and dissolved oxygen concentration at Rough and Ready Island. To establish a model calibrated for dissolved oxygen, the Link-Node parameters that influence dissolved oxygen (temperature, ammonia-nitrogen, biochemical oxygen demand, and phytoplankton) were also considered.

Hydrodynamic calibration results are presented for water surface elevation (ft) and discharge (ft<sup>3</sup>/sec) at Rough and Ready Island. Water quality calibration results are presented for temperature, ammonia-nitrogen, biochemical oxygen demand, phytoplankton and dissolved oxygen concentration (mg/L). Since water quality at Rough and Ready Island is tidally influenced, water quality calibration results are presented for Buckley Cove (downstream/ocean side of RRI) and Stockton (upstream/upland of RRI) in addition to at RRI.

Following calibration, the model can be used to explain why the water quality behaved as observed. Such understanding is crucial to the formulation of adaptive water quality management plans. After the calibration, the model can be used to calculate the maximum daily loads of oxygen consuming materials to meet the DO standard.

## **2.1 Hydrodynamic simulation at Rough and Ready Island**

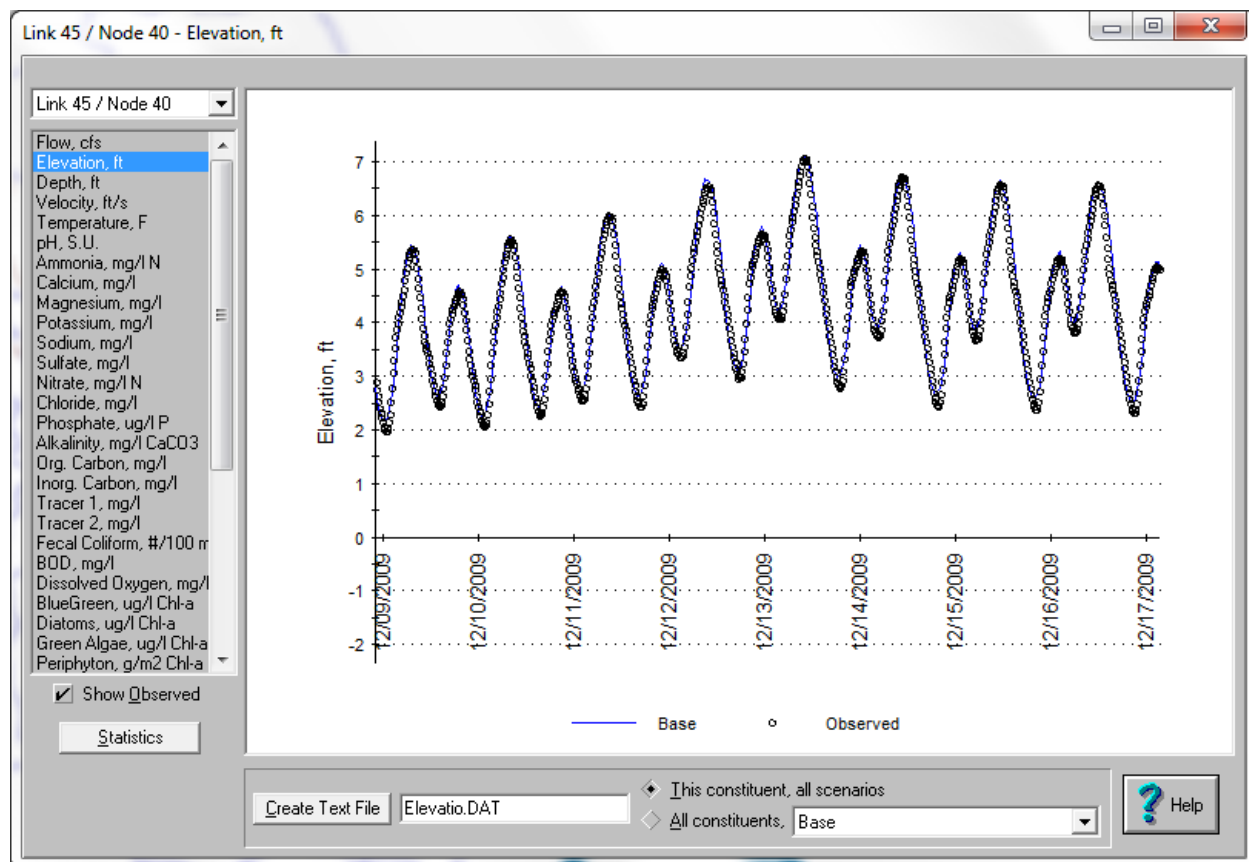
Accurate simulation of water quality parameters is only possible if the simulated hydrodynamics are also accurate. Therefore, Systech invested significant resources in synthesizing tidal boundary input files, estimating river inputs to the lower San Joaquin River, and updating the Link-Node model with the best available bathymetry information. Figure 0.1 shows the link-node system of the San Joaquin River DO model. The San Joaquin River flow enters the Link-Node model domain at node 1. The DWSC is located at Nodes 30, 39, 40, 44, 59, 60, 61, 91, 92, 95, and 96. The Link-Node tidal boundary inputs are located at nodes 70, 94, and 96.

The Tidal boundary input files were created using data obtained from the California Data Exchange Center (CDEC). Water surface elevation data were obtained for Turner Cut near Holt (CDEC Station TRN), the San Joaquin River at Rough and Ready Island (CDEC station RRI) and the San Joaquin River at Venice Island (CDEC station VNI). Each of these data sets were carefully reviewed for erroneous data points. Missing data were filled using data from adjacent locations, accounting for differences in tide timing between sites. The timing and stage of high and low tides were determined from the TRN, RRI, and VNI time series for the locations corresponding to nodes 70, 94, and 96. These data sets were assembled for the time period between 10/01/2004 and 9/30/2012.

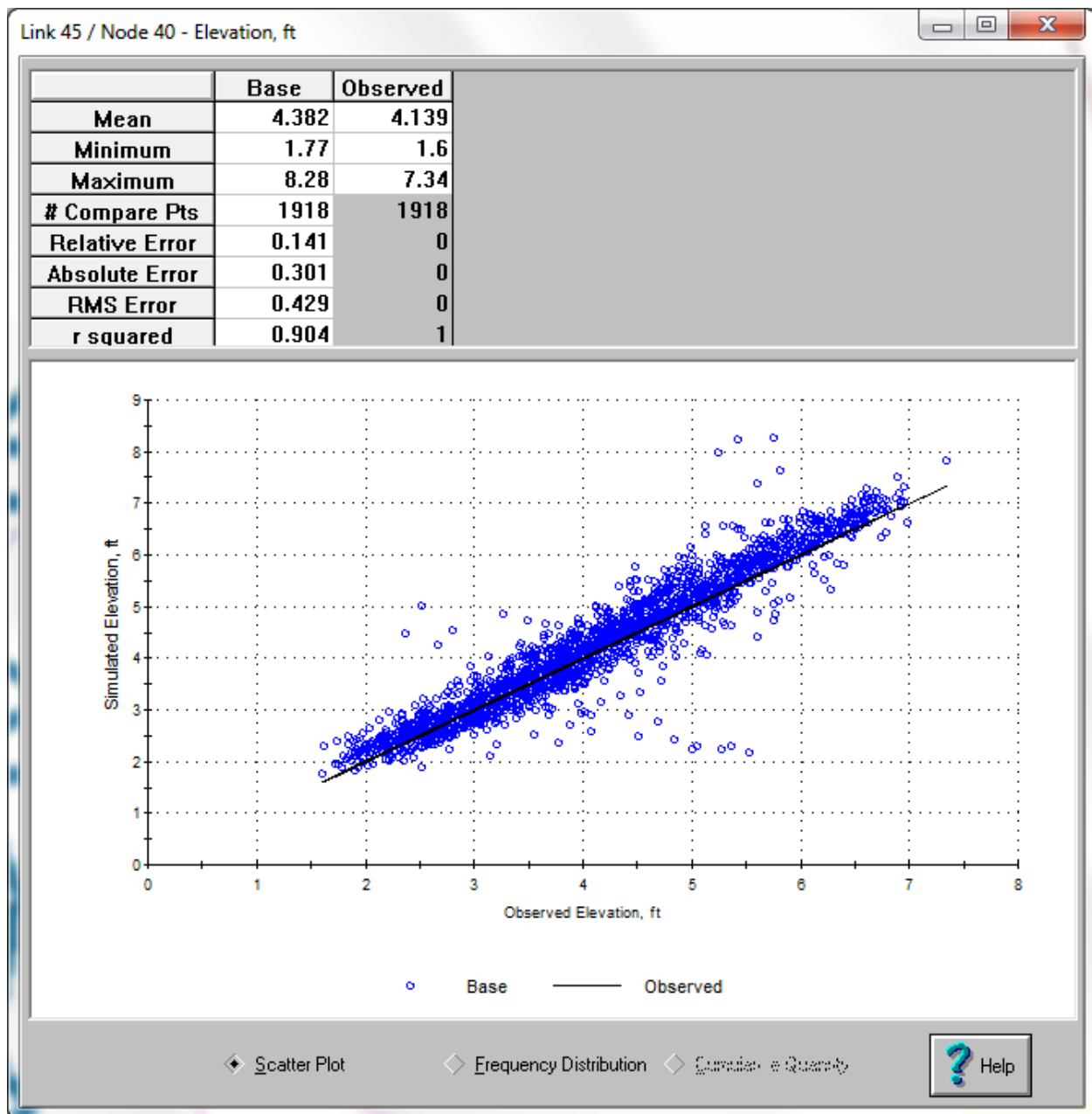
Previous versions of the San Joaquin River DO model only accounted for flow and associated water quality inputs from the Stockton wastewater treatment plant discharge and the San Joaquin River at the upstream boundary of the Link-Node model domain. The capabilities of the Link-Node model have been expanded to include discharge and water quality inputs from the other sloughs, creeks and rivers that are hydrologically connected to the model domain. These sources include 14 Mile Slough, Bear Creek, Pixley Slough, Mosher Slough, the Calaveras River, Mormon Slough, Duck Creek, Littlejohns Creek, French Camp Slough, and the U-Tube Aeration project facility. Time series of flow and water quality for each of the sloughs, creeks and rivers were created using a combination of observed data and simulation results from the Sacramento River/Delta east side tributaries application of WARMF. Observed data collected as part of this project were combined with other sources (CA Department of Water Resources, US EPA, USGS) and used to populate the Link-Node boundary water quality file when available. Simulation output from the Sacramento River/Delta east side WARMF application were used in the absence of observed data to populate the Link-Node boundary water quality file.

Channel bathymetry affects the timing of tidal cycles within the model domain, current velocities, and the quantity of water moving through the channels on the ebb and flood tides. In order to more accurately depict the geometry of channels within the Link-Node model domain, channel geometries were recalculated for each model segment. The new dimensions were calculated using a geographic information system and a digital elevation model (DEM) of the estuary created and distributed by the US Geological Survey Water Resources Division. The DEM was developed from a database of point soundings assembled by the California Department of Water Resources (available at: <http://modeling.water.ca.gov/delta/models/dsm2/tools/csdp/index.html>), and has a horizontal resolution of 10 m and a vertical resolution of 0.1 Feet.

Figure 2 and Figure 3 illustrate the measured and simulated tidal elevation at Rough and Ready Island. Figure 2 graphically shows the relationship between measured and simulated tidal elevation over a 7-day period. These seven days were selected at random and results are similar for all days throughout the simulation time frame. Figure 3 shows the tidal elevation simulation statistics calculated by WARMF using measured (CDEC Station RRI) data from October 2005 through December 2010. Both figures illustrate that Link-Node is doing an excellent job of simulating water surface elevation in the vicinity of Rough and Ready Island.



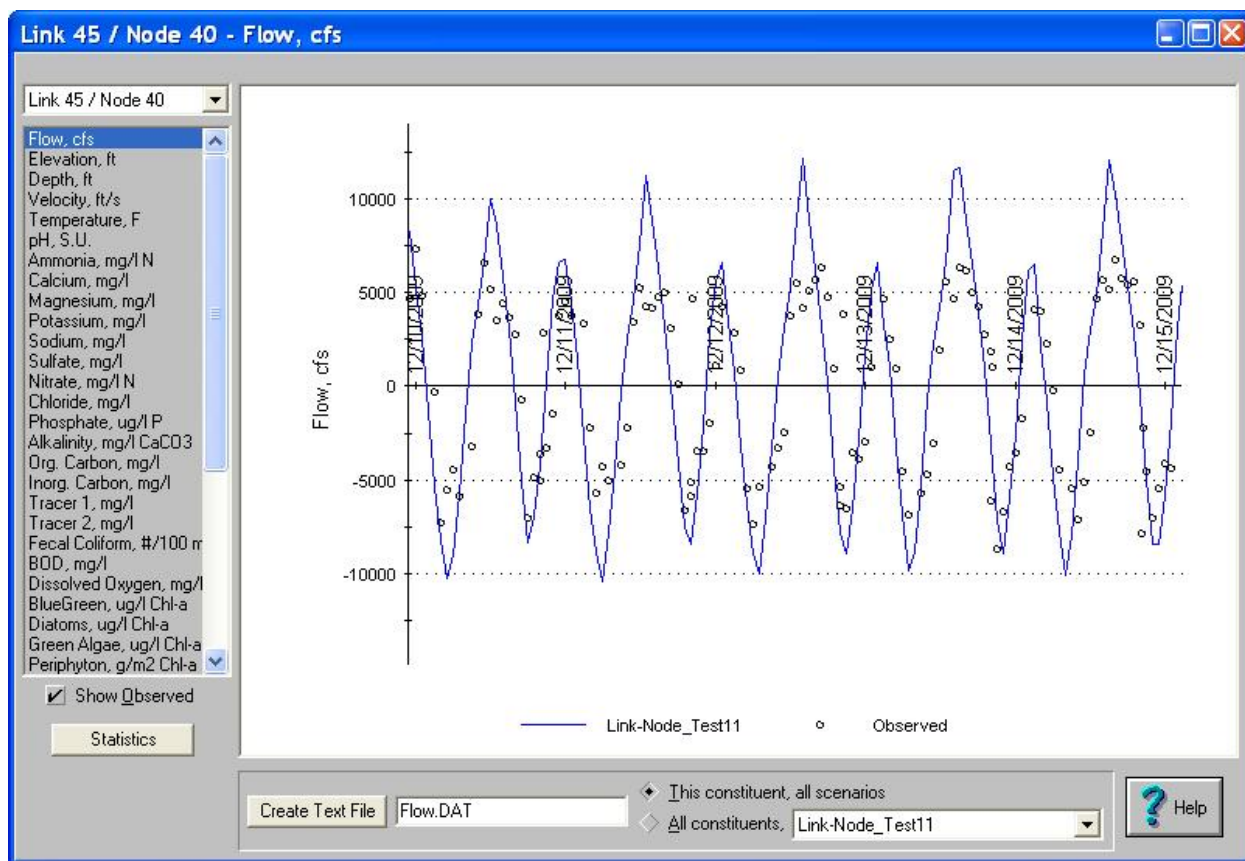
**Figure 2.** Link-Node tidal elevation simulation results (blue line) and observed data (black circles) at Rough and Ready Island, December 9-17, 2009.



**Figure 3.** Link-Node tidal elevation simulation statistics, Rough and Ready Island, October 2005 through December 2010.

Figure 4 illustrates the measured and simulated San Joaquin River discharge at Rough and Ready Island over a 6-day period. Unfortunately, the number of inconsistencies between the measured elevation and discharge data collected at RRI are too great to statistically evaluate the fit of simulated discharge with measured data. Figure 4 does illustrate that the magnitude of simulated quantity of water flowing past Rough and Ready Island on both the ebb and flood

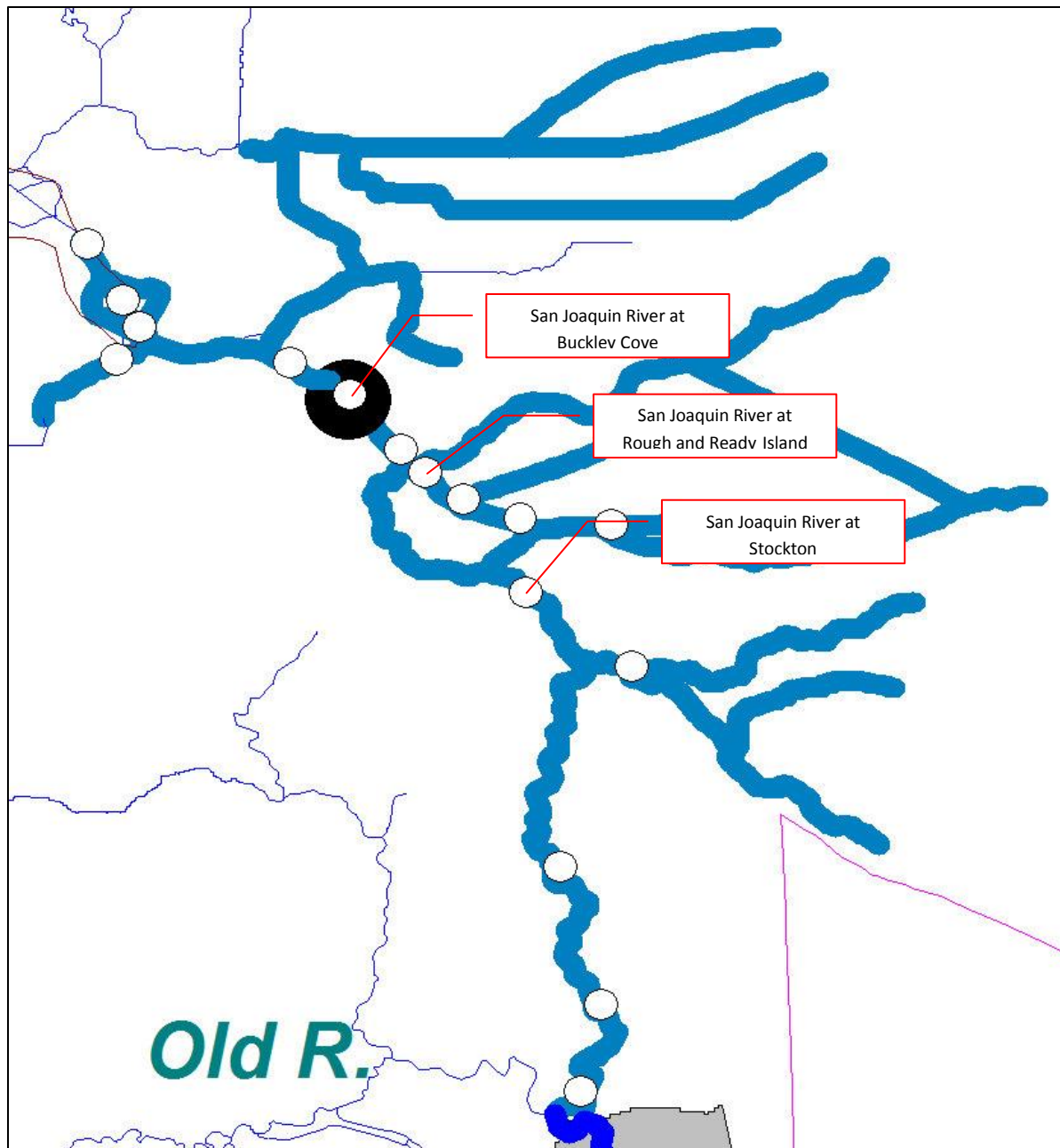
tide is generally too great. Since the simulation of tidal elevation is quite good, errors in river discharge simulation are likely related to a combination of discharge measurement error and the bathymetry data used within Link-Node to calculate channel cross-sectional area. The bathymetry data used to estimate the channel dimensions are considered to be the best available, so the primary source of model error can likely be attributed to the interpretation of the bathymetry data. For example, the channel depth entered into the Link-Node model was calculated as the maximum value identified at the corresponding location in the USGS bathymetry DEM. Since Link-Node fits the specified channel depth and width to a rectangular cross-section, the calculated cross-sectional area used in Link-Node is likely an over-estimation of the true channel cross-section. The simulation of discharge could likely be improved by reducing the channel cross-sectional area until the simulated flow matched the observed flow on both the ebb and flood tides. Alteration of the channel cross-section would affect the water quality simulation results, so it is likely that the water quality calibration would have to be adjusted following any changes in the channel cross-section data that are used in the model.



**Figure 4.** Link-Node discharge simulation results (blue line) and observed data (black circles) at Rough and Ready Island, December 10-15, 2009.

## 2.2 Water Quality Simulation

Accurate and precise simulation of dissolved oxygen in the Stockton Deep Water Shipping Channel is dependent upon the ability of the Link-Node model to accurately simulate the water quality constituents that affect dissolved oxygen concentrations. These constituents include temperature, ammonia-nitrogen, biochemical oxygen demand, and phytoplankton. It is necessary for Link-Node to accurately simulate each of these chemical constituents at locations upstream and downstream of Rough and Ready Island. The following sections provide results for temperature, ammonia-nitrogen, biochemical oxygen demand, phytoplankton, and dissolved oxygen. Results are presented for three locations within the Link-Node model domain: the San Joaquin River at Stockton, Rough and Ready Island, and Buckley Cove (Figure 5).

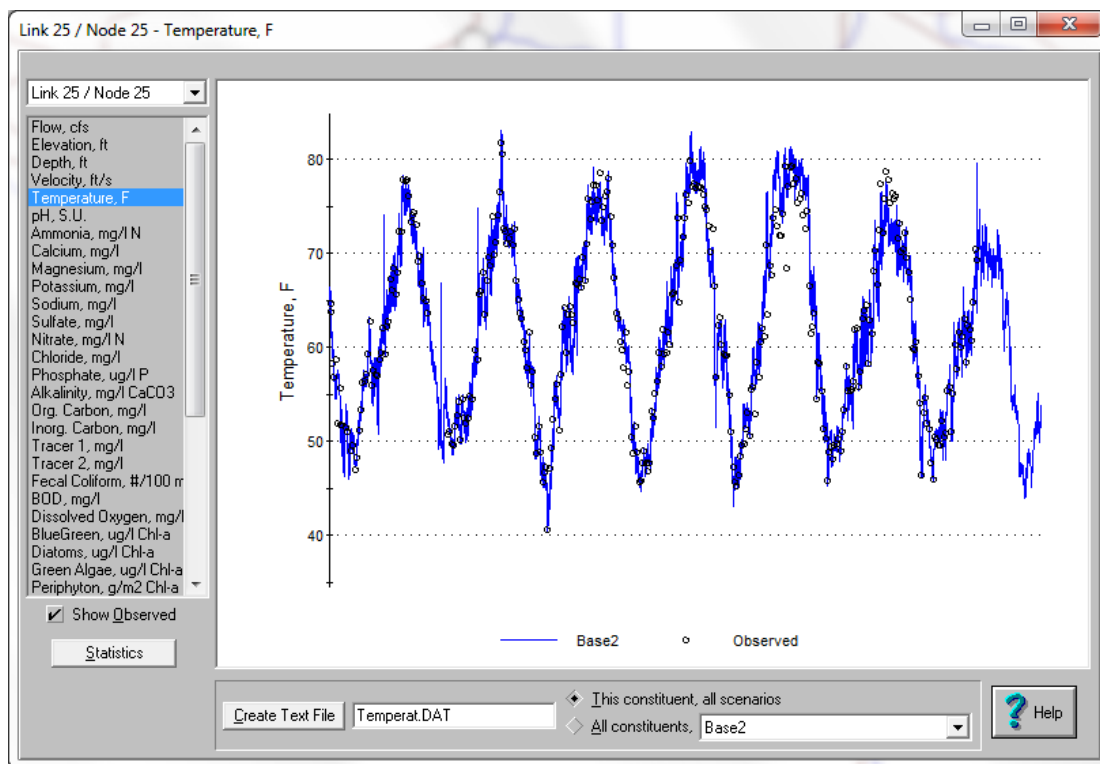


**Figure 5.** Water quality sampling sites located within the Link-Node model domain

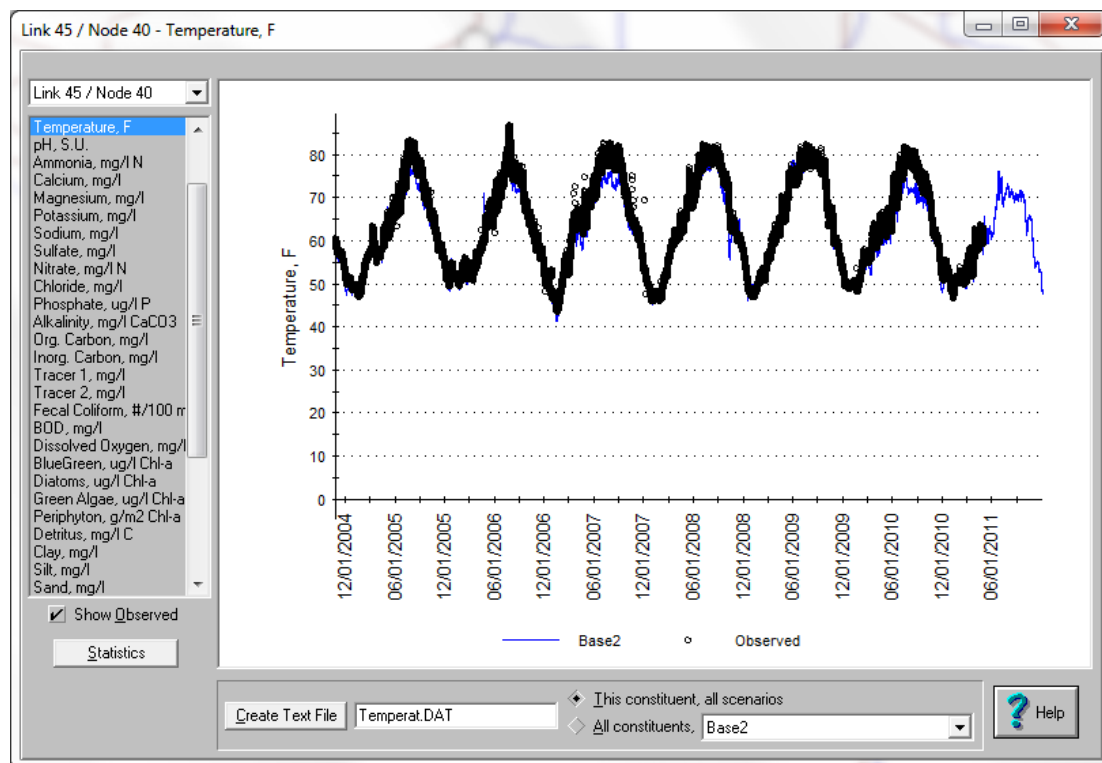
### 2.2.1 Temperature Simulation

Accurate simulation of water temperature in the DWSC is essential to accurate simulation of other water quality parameters since temperature affects chemical reaction rates, biological activity, and dissolved oxygen saturation levels. Figure 6 through Figure 8 illustrate the comparison between the Link-Node temperature simulation results and the measured water temperature at Stockton, Rough and Ready Island and Buckley Cove respectively. The figures

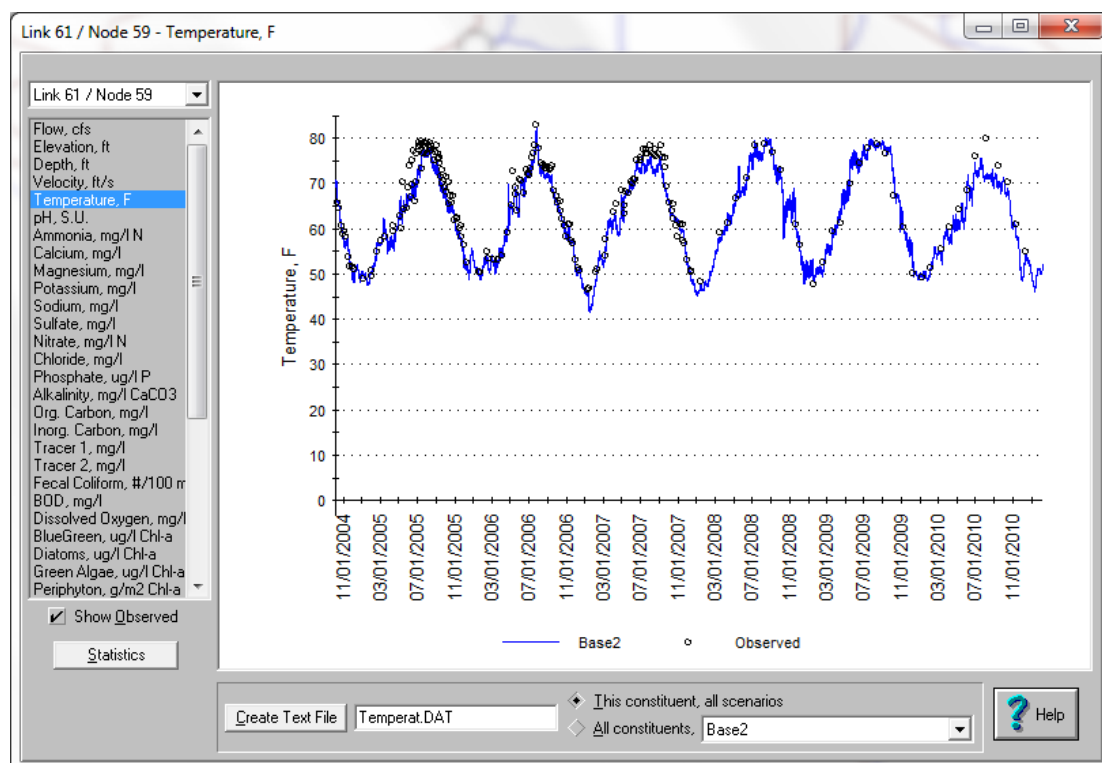
indicate that Link-Node is simulating water temperature with a high degree of precision and accuracy upstream of and throughout the DWSC. The observed mean value and the simulation relative and absolute error are provided in Table 1.



**Figure 6.** Link-Node temperature simulation results (blue line) and observed data (black circles) for the San Joaquin River at Stockton



**Figure 7.** Link-Node temperature simulation results (blue line) and observed data (black circles) for the San Joaquin River at Rough and Ready Island.



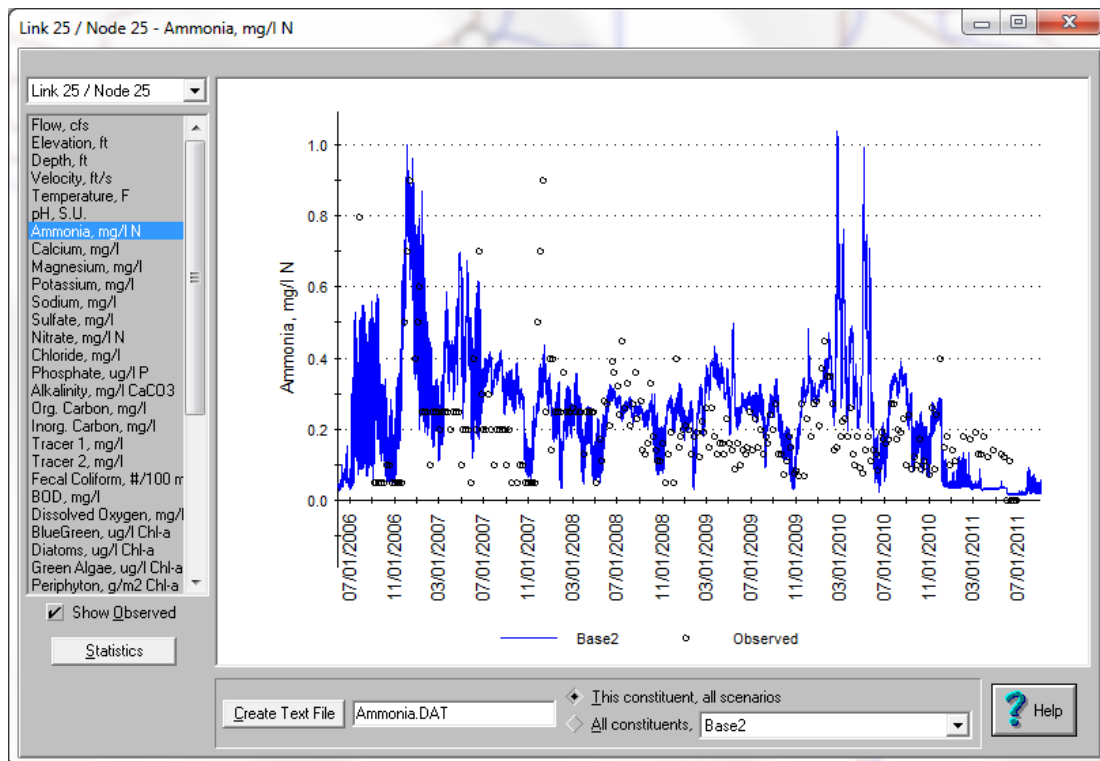
**Figure 8.** Link-Node temperature simulation results (blue line) and observed data (black circles) for the San Joaquin River at Buckley Cove.

**Table 1.** Link-Node simulation statistics for temperature

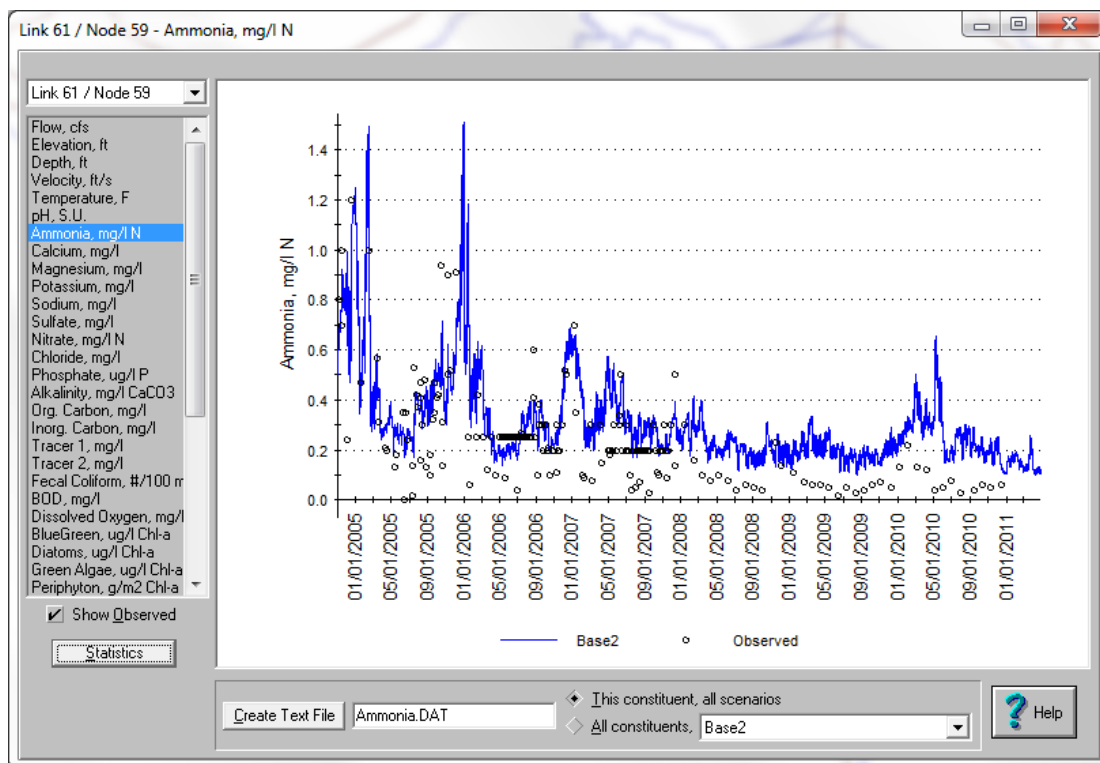
	San Joaquin River at Stockton	San Joaquin River at Rough and Ready Island	San Joaquin River at Buckley Cove
Mean Observed (Celcius)	16.8	17.3	19.2
Relative Error	0.1	-0.7	-0.9
Absolute Error	0.8	0.9	1.1

## 2.2.2 Ammonia-Nitrogen Simulation

Figure 9 and Figure 10 illustrate the comparison between the Link-Node ammonia-nitrogen simulation results and the measured concentrations at Stockton and Buckley Cove respectively. Results indicate that Link-Node is accurately simulating the trends in ammonia-nitrogen at both locations. Simulated concentrations are generally slightly greater than the observations at both locations. The observed mean value and the simulation relative and absolute error percentages are provided in Table 2.



**Figure 9.** Link-Node ammonia simulation results (blue line) and observed data (black circles) for the San Joaquin River at Stockton.



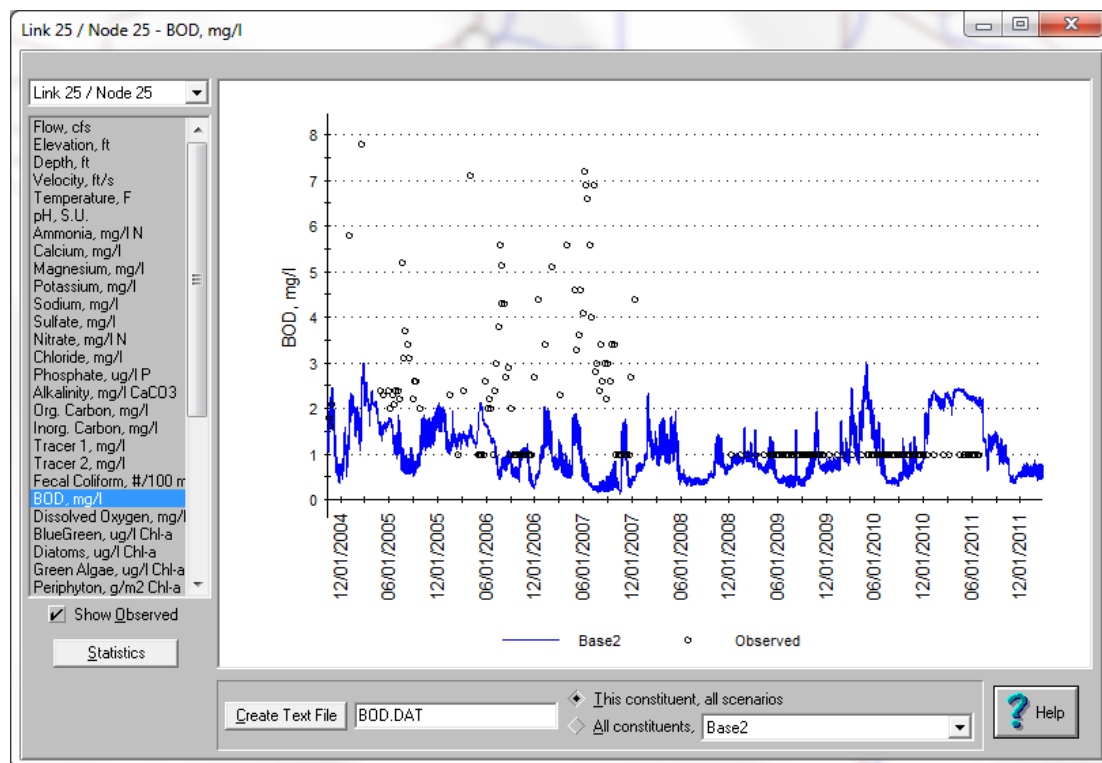
**Figure 10.** Link-Node ammonia simulation results (blue line) and observed data (black circles) for the San Joaquin River at Buckley Cove.

**Table 2.** Link-Node simulation statistics for ammonia-nitrogen

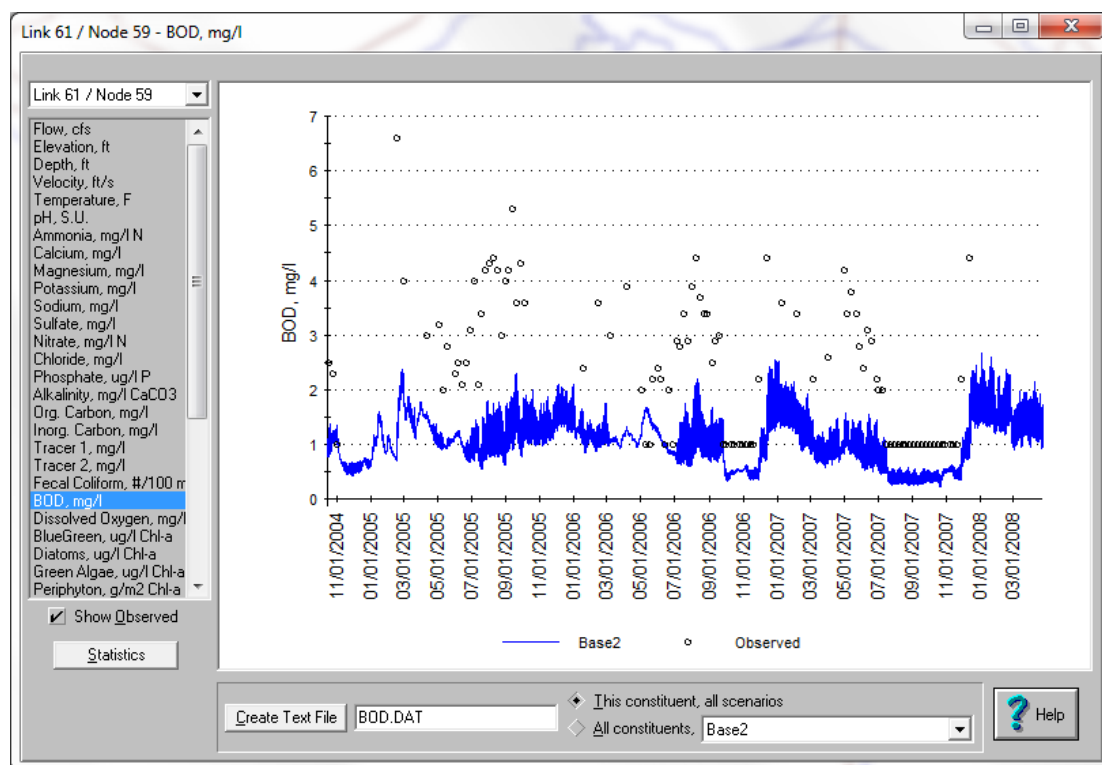
	San Joaquin River at Stockton	San Joaquin River at Rough and Ready Island	San Joaquin River at Buckley Cove
Mean Observed (mg/L)	0.20	No Data	0.28
% Relative Error	28%		22%
% Absolute Error	59%		57%

### 2.2.3 Biochemical Oxygen Demand (BOD) Simulation

Figure 11 and Figure 12 illustrate the comparison between the Link-Node biochemical oxygen demand simulation results and the measured BOD concentrations at Stockton and Buckley Cove respectively. The observed mean value and the simulation relative and absolute error percentages are provided in Table 3. At both locations, simulated BOD concentration is often considerably lower than the observed concentration. An important source of this discrepancy is the difference between the constituents contributing to BOD concentration in WARMF and Link-Node versus the observations. The concentration of BOD in a water sample is comprised of all oxygen consuming materials that are present within the water sample including living phytoplankton, which will ultimately die and decay, consuming oxygen during a BOD sample analysis. In WARMF and Link-Node, the concentration of BOD does not include living phytoplankton and therefore simulated BOD concentrations are expected to be less than the observed concentrations when phytoplankton are present in the water column. The BOD simulated by WARMF and Link-Node is carbonaceous, so it also excludes the oxygen demand of ammonia nitrification. It is not possible to calculate the contribution of phytoplankton to the BOD observations. However, analysis of the observed BOD data collected at Buckley Cove suggest that the average observed seasonal BOD concentrations are highest during the winter and lowest during the summer and fall. This trend may suggest that the death and decay of phytoplankton that occurs predominantly during the winter months may significantly contribute to the discrepancy between the observed and simulated BOD concentrations at Buckley Cove. The BOD data collected from the San Joaquin River at Stockton suggest that upgrades made to the Stockton Municipal Wastewater Treatment plant were effective in reducing in-stream BOD levels in the San Joaquin River upstream of the DWSC. Figure 12 illustrates the reduction in BOD that occurred in 2008 as a result of the plant upgrades.



**Figure 11.** Link-Node biochemical oxygen demand simulation results (blue line) and observed data (black circles) for the San Joaquin River at Stockton.



**Figure 12.** Link-Node biochemical oxygen demand simulation results (blue line) and observed data (black circles) for the San Joaquin River at Buckley Cove.

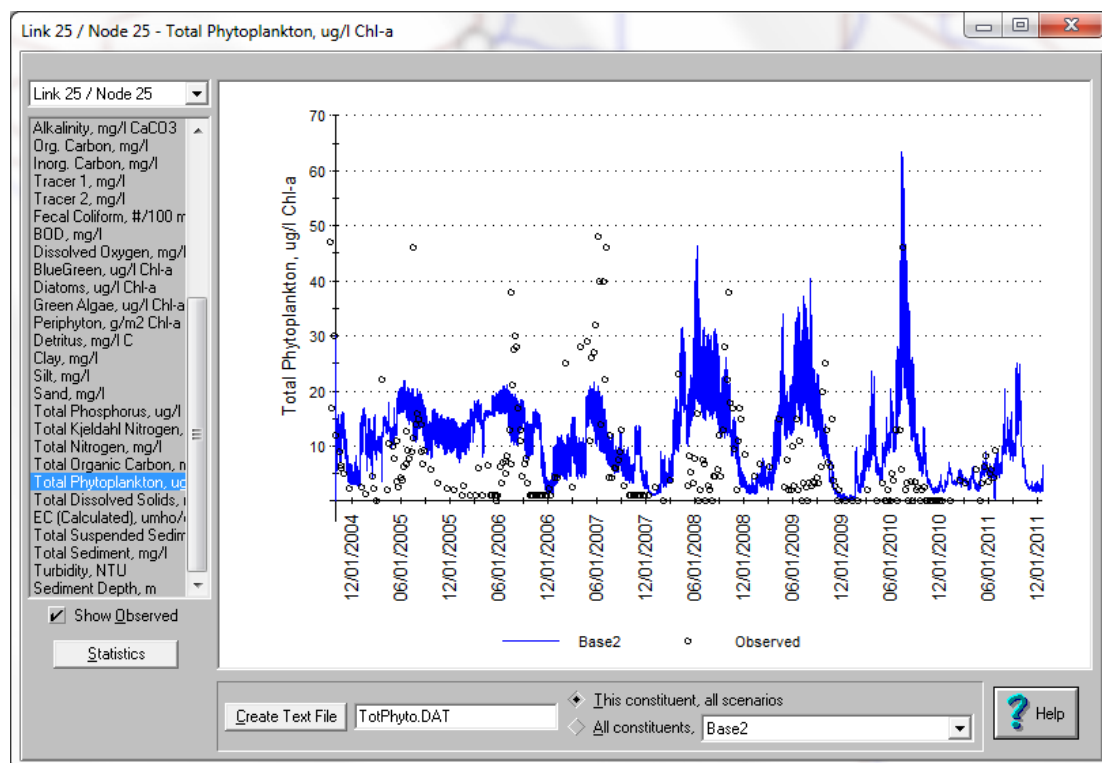
**Table 3.** Link-Node simulation statistics for biochemical oxygen demand

	San Joaquin River at Stockton	San Joaquin River at Rough and Ready Island	San Joaquin River at Buckley Cove
Mean Observed (mg/L)	1.96	No Data	2.54
% Relative Error	-50%		-65%
% Absolute Error	68%		66%

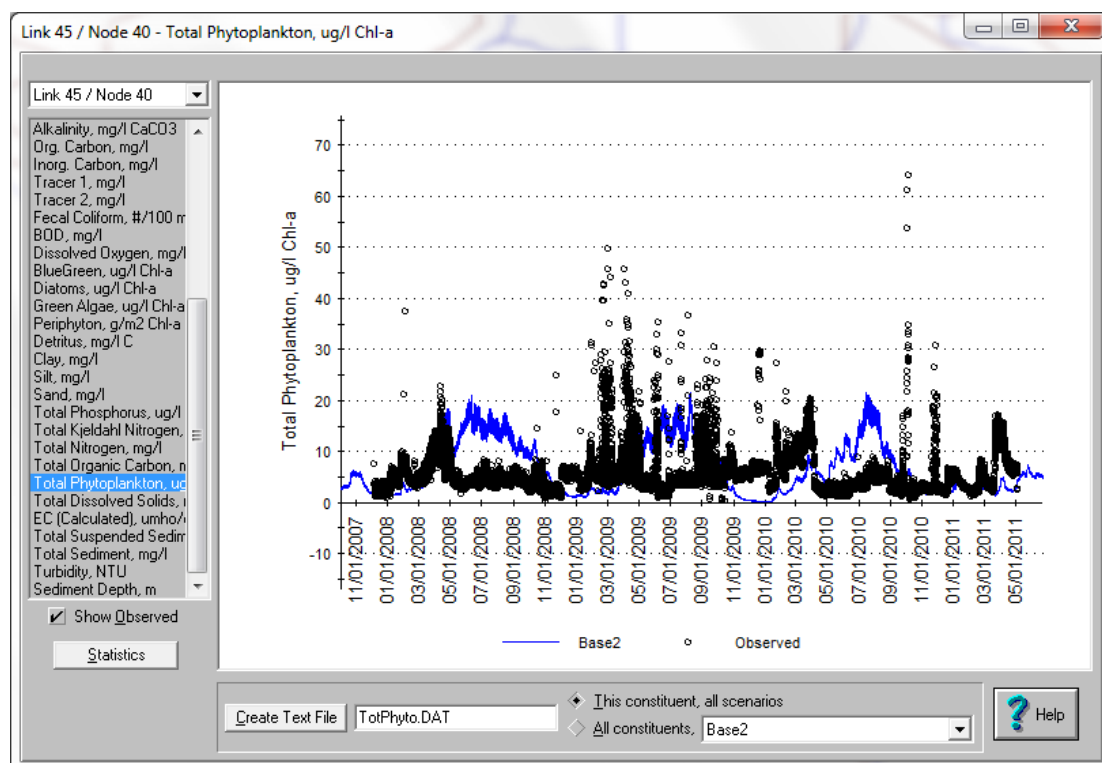
## 2.2.4 Phytoplankton Simulation

Figure 13 through Figure 15 illustrate the comparison between the Link-Node phytoplankton simulation results and the measured phytoplankton concentrations at Stockton, Rough and Ready Island, and Buckley Cove respectively. The observed mean value and the simulation relative and absolute error percentages are provided in Table 4. The observed data indicate that phytoplankton concentration in the San Joaquin River is highly variable, with concentrations commonly oscillating between 5 and 50 ug/L in a one-week time period. The figures demonstrate that the simulated concentrations of phytoplankton are somewhat less variable than the measured values, but are generally within the range of observed values. Link-Node is simulating the correct annual pattern in phytoplankton abundance at Stockton and

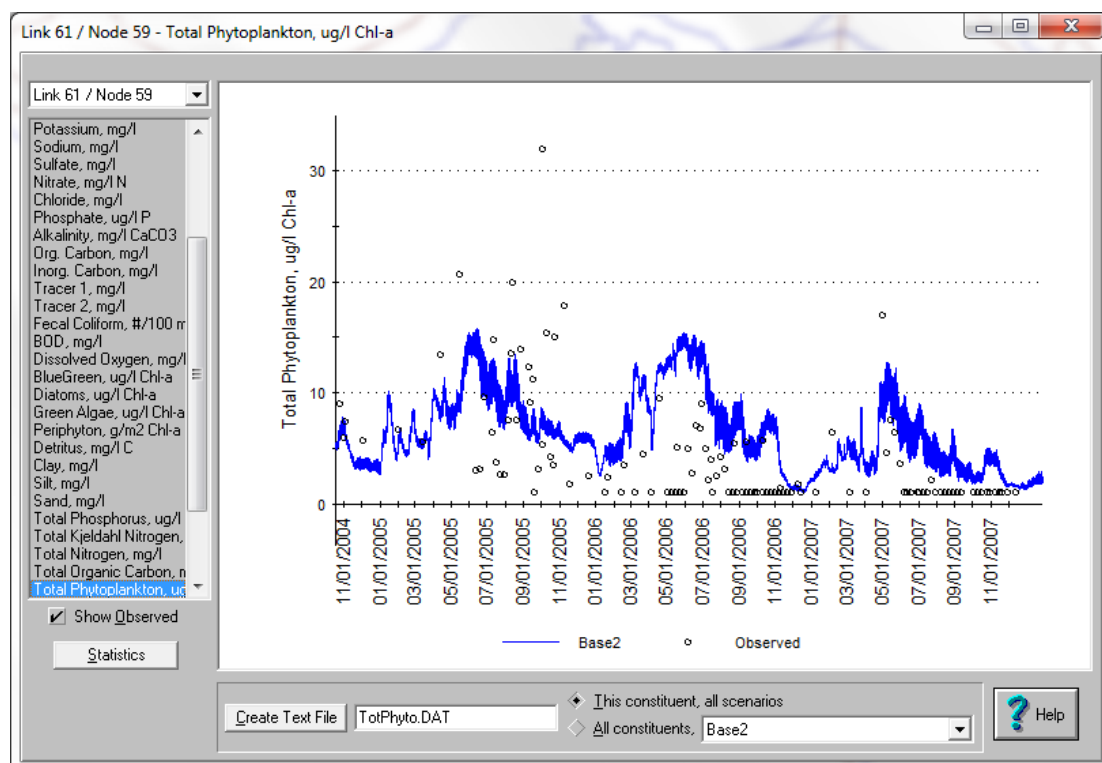
Buckley Cove, but is only capturing a portion of the peaks in phytoplankton abundance at Rough and Ready Island. The discrepancy between observed and simulated concentrations at Rough and Ready Island is likely the result of a combination of phytoplankton growth not captured by the simulation and measurement error (a data sonde was used to collect the Rough and Ready Island data).



**Figure 13.** Link-Node phytoplankton simulation results (blue line) and observed data (black circles) for the San Joaquin River at Stockton



**Figure 14.** Node phytoplankton simulation results (blue line) and observed data (black circles) for the San Joaquin River at Rough and Ready Island



**Figure 15.** Link-Node phytoplankton simulation results (blue line) and observed data (black circles) for the San Joaquin River at Buckley Cove.

**Table 4.** Link-Node simulation statistics for total phytoplankton

	San Joaquin River at Stockton	San Joaquin River at Rough and Ready Island	San Joaquin River at Buckley Cove
Mean Observed (ug Chl A/L)	7.52	5.62	4.41
% Relative Error	65%	22%	60%
% Absolute Error	123%	101%	110%

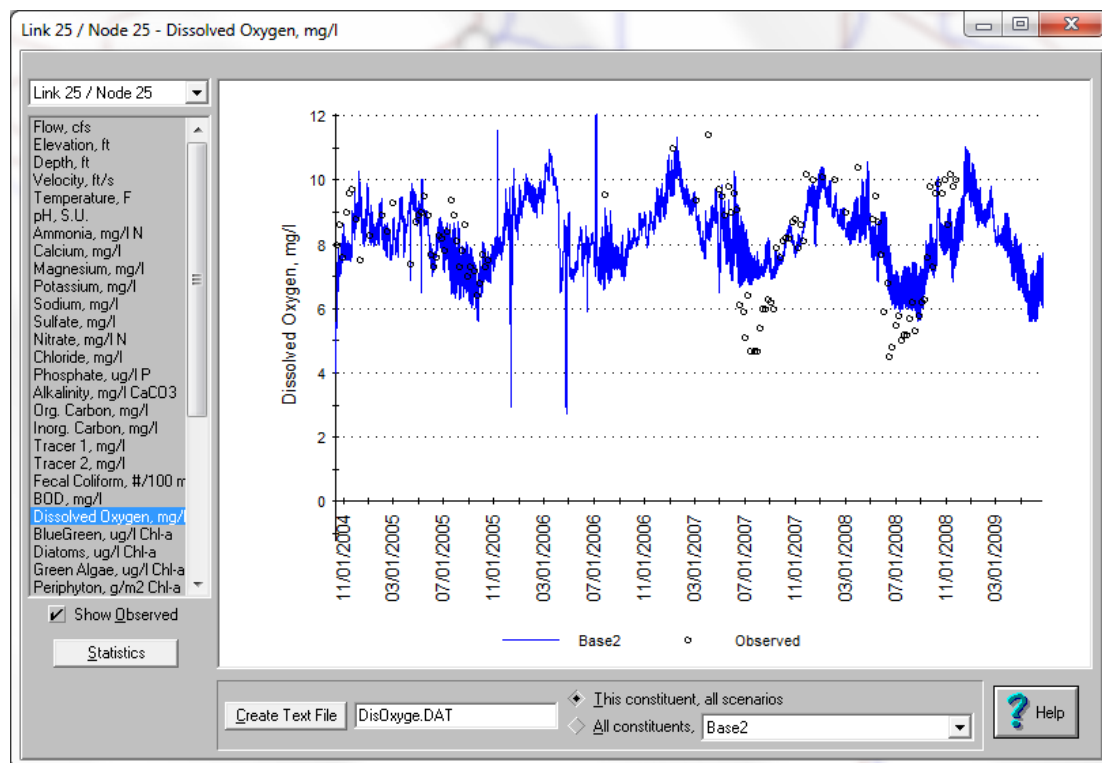
### 2.2.5 Dissolved Oxygen Simulation

Considerable effort has been expended to produce an accurate and precise simulation of dissolved oxygen concentrations in the DWSC. Initial model parameter sensitivity analysis indicated that DO simulation output is highly sensitive to the model's biochemical oxygen demand decay and mechanical aeration algorithms and parameters. Wind speed data from the Rough and Ready Island sensor was obtained, screened for errors, and adjusted to reflect wind speed at 10 meters above the water surface (a requirement of the aeration algorithm). The aeration equation employed within link-node was updated to a form specifically developed for estuary aeration calculation. For calibration purposes, all measured dissolved oxygen values greater than the theoretical temperature-dependent dissolved oxygen saturation condition

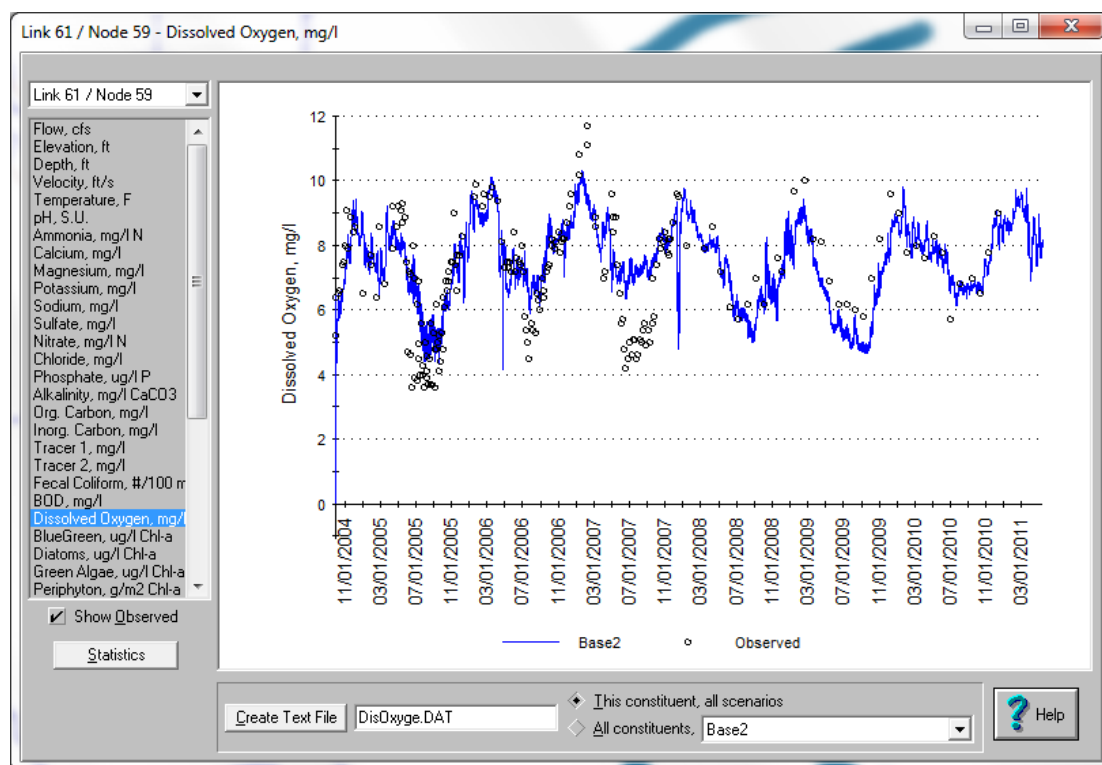
were eliminated from the measured DO dataset. The Link-Node model is being used to evaluate the timing of, and pollutant sources associated with low dissolved oxygen concentrations in the DWSC. Supersaturated dissolved oxygen measurements were removed from the RRI dataset so that the model calibration could be focused on normal and below normal dissolved oxygen concentration conditions.

The Link-Node model calibration was accomplished by optimizing the Aeration Adjustment Factor and the BOD decay rate to minimize the simulation relative and absolute error statistics. The Aeration Adjustment Factor affects dissolved oxygen by linearly increasing (value>1) or decreasing (value<1) the contribution of aeration to the depth-averaged dissolved oxygen concentration). BOD is the consumption (or decrease) of DO, caused either by microorganisms as they decompose organic material or by chemical oxidation. The concentration of BOD in a water sample will decrease over time. The rate at which the BOD concentration decreases is the BOD decay rate. The calibration was performed by making changes to either the aeration adjustment factor or the BOD decay rate and rerunning the model. If the changes resulted in decreased relative and absolute error the changes were retained. If the changes caused an increase in the model error they were discarded and a new value was selected. The calibration was considered to be optimized when an increase or decrease in either the aeration adjustment factor or the BOD decay rate caused an increase in the model error statistics

Figure 16 and Figure 17 illustrate the comparison between the Link-Node dissolved oxygen simulation results and the measured dissolved oxygen concentrations at Stockton and Buckley Cove respectively. Both figures demonstrate that Link-Node is accurately simulating dissolved oxygen concentration over the majority of the simulation timeframe, but is not capturing the extreme values. During the summers of 2007 and 2008, observed dissolved oxygen concentrations in the San Joaquin River at Stockton decreased to 4.5 mg/L while simulated concentrations remained consistent with other simulation years, decreasing to a minimum of 6 to 7 mg/L. A similar trend is apparent in the results from Buckley Cove. During the summers of 2005, 2006, and 2007 observed dissolved oxygen levels reached minimum values in the vicinity of 4 mg/L while simulated minimum concentrations ranged from 4.5 mg/L in 2005 to 6.5 mg/L in 2007.

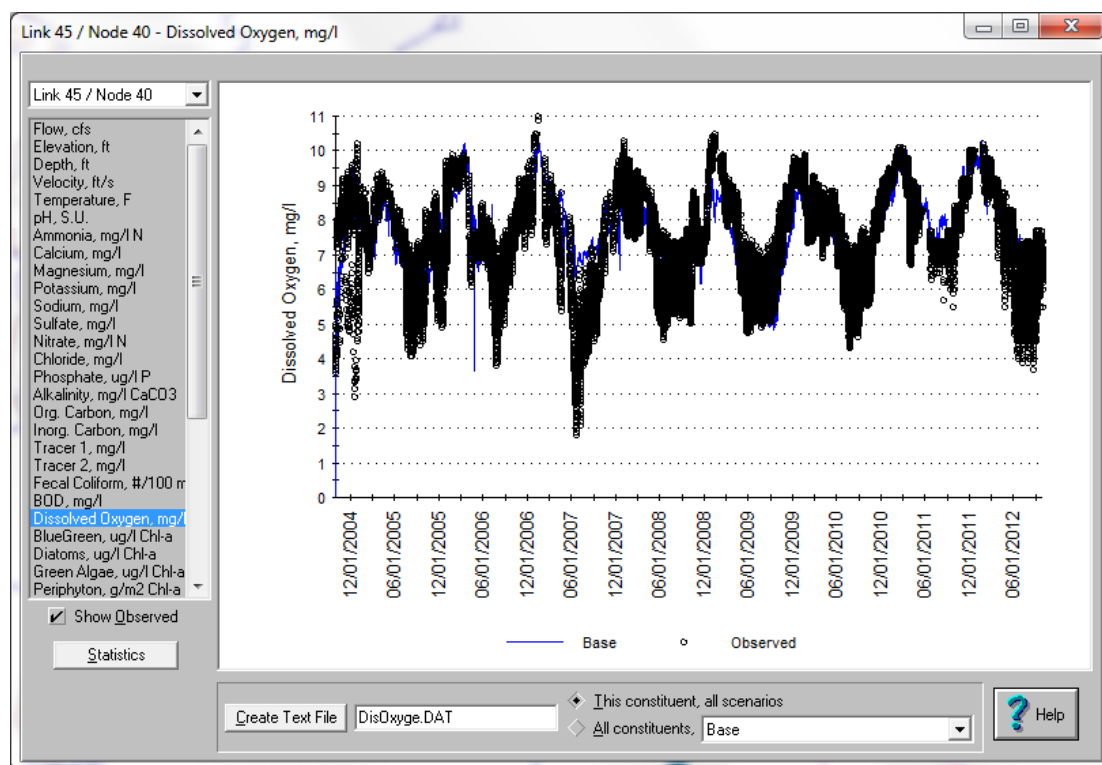


**Figure 16.** Link-Node dissolved oxygen simulation results (blue line) and observed data (black circles) for the San Joaquin River at Stockton.



**Figure 17.** Link-Node dissolved oxygen simulation results (blue line) and observed data (black circles) for the San Joaquin River at Buckley Cove.

Figure 18 illustrates the comparison between the Link-Node dissolved oxygen simulation results and the measured dissolved oxygen concentrations at Rough and Ready Island. In general the calibrated model is doing a good job of simulating trends in DO concentrations and is estimating the magnitude of the DO concentrations well. Dissolved oxygen simulation statistics for Stockton, Rough and Ready Island, and Buckley Cove are provided in Table 5. The relative error statistics indicate that Link-Node is accurately simulating dissolved oxygen concentrations at each location over the duration of the simulation. The absolute error is consistent across the three locations, ranging from 10% - 13%. Low absolute error statistics indicate that the model is simulating dissolved oxygen concentrations with a high degree of precision during the 2004-2012 timeframe.



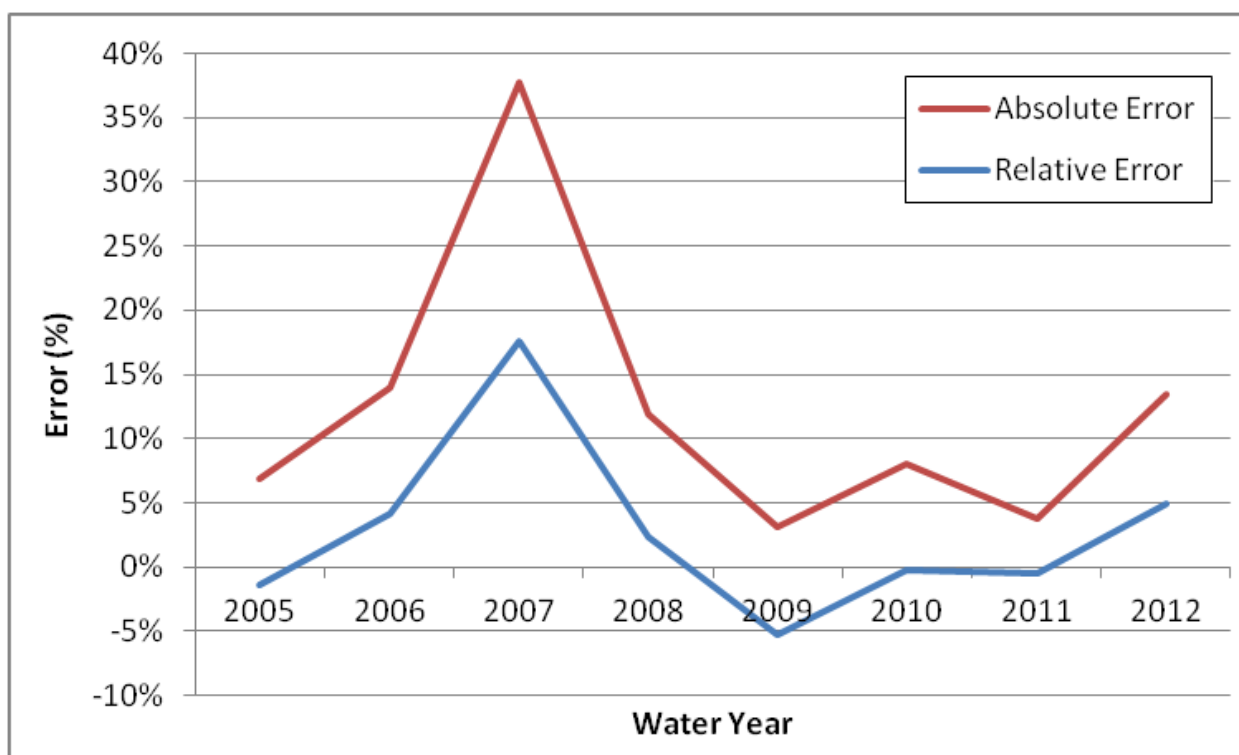
**Figure 18.** Link-Node dissolved oxygen simulation results (blue line) and observed data (black circles) at Rough and Ready Island, October 2004 through September 2012.

**Table 5.** Link-Node simulation statistics for dissolved oxygen

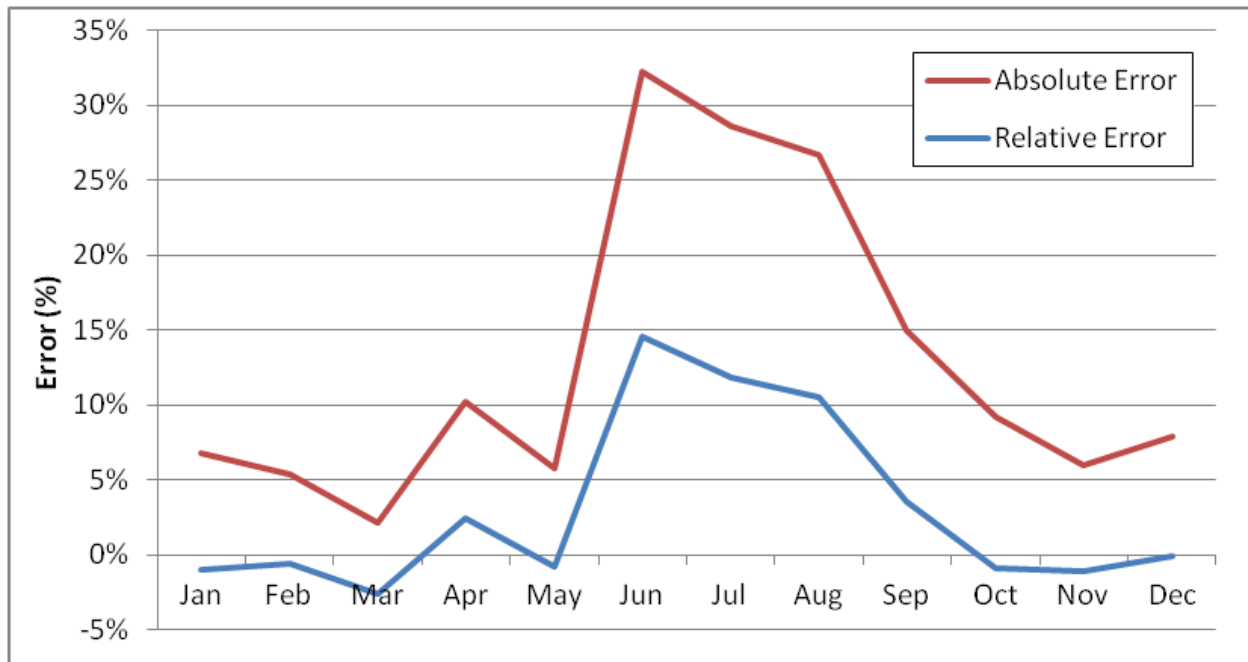
	San Joaquin River at Stockton	San Joaquin River at Rough and Ready Island	San Joaquin River at Buckley Cove
Mean Observed (mg/L)	7.9	7.4	7.0
% Relative Error	-3%	2%	2%
% Absolute Error	13%	10%	13%

The analysis of the dissolved oxygen simulation relative and absolute error statistics is further broken down to investigate annual and seasonal trends in the statistics. Figure 19 illustrates the relative and absolute error associated with dissolved oxygen simulation at Rough and Ready Island by water year. The magnitude of relative error is at or below 5% for each of the simulation years 2005, 2006, and 2008-2012. Absolute error follows a similar trend with low values calculated for all of the simulation years with the exception of 2007. The highest simulation error occurred during 2007 when observed dissolved oxygen levels at Rough and Ready Island fell to concentrations in the range of 2 - 6 mg/L during the summer months. Simulated dissolved oxygen concentrations during this time period were within the range of 6 - 7.5 mg/L. The simulated values were consistently greater than the observed values during the summer of 2007, leading to greater relative and absolute error during the 2007 water year.

Figure 20 illustrates the relative and absolute error associated with dissolved oxygen simulation at Rough and Ready Island by month. The magnitude the relative error is at or below 5% for all months except June, July, and August when the relative error increases to between 10 and 15%. A positive relative error indicates that the simulated values are, on average, between 10 and 15% greater than the dissolved oxygen observations. The simulated dissolved oxygen concentration could be decreased to match the summertime dissolved oxygen observations, but it is likely that such changes would increase the relative and absolute error when calculated over the entire simulation timeframe. It would also be possible to increase the simulated algae respiration which would lead to decreased dissolved oxygen concentrations during the summer months when algae are most abundant.



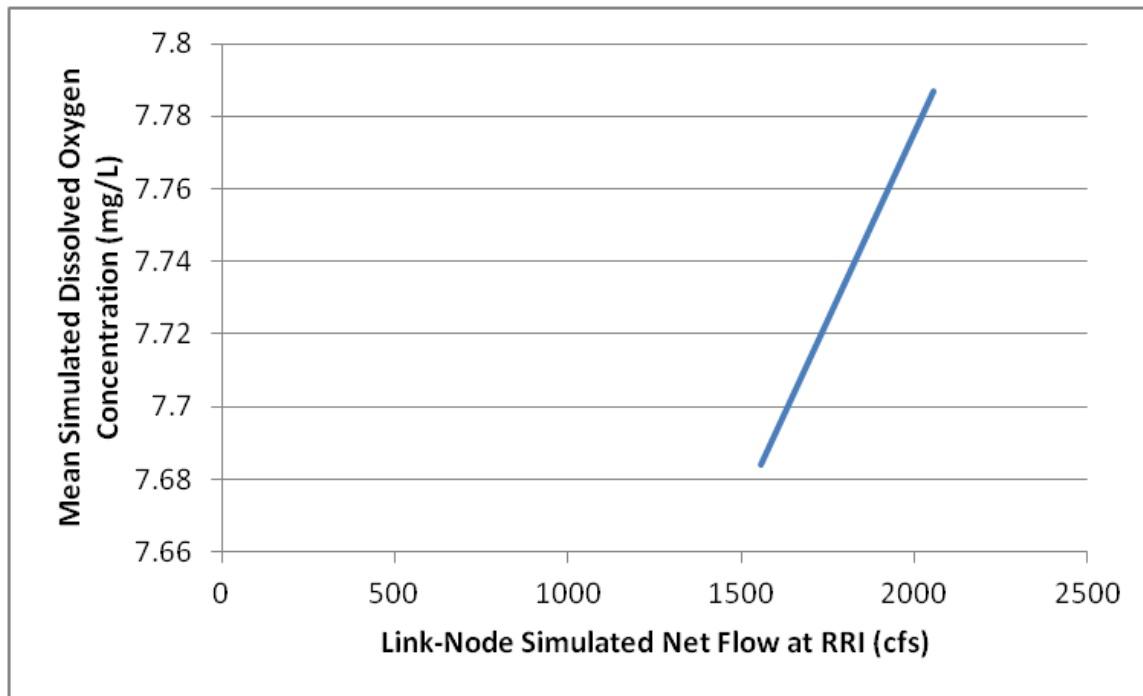
**Figure 19.** Link-Node dissolved oxygen relative and absolute error simulation statistics, calculated by water year, Rough and Ready Island,



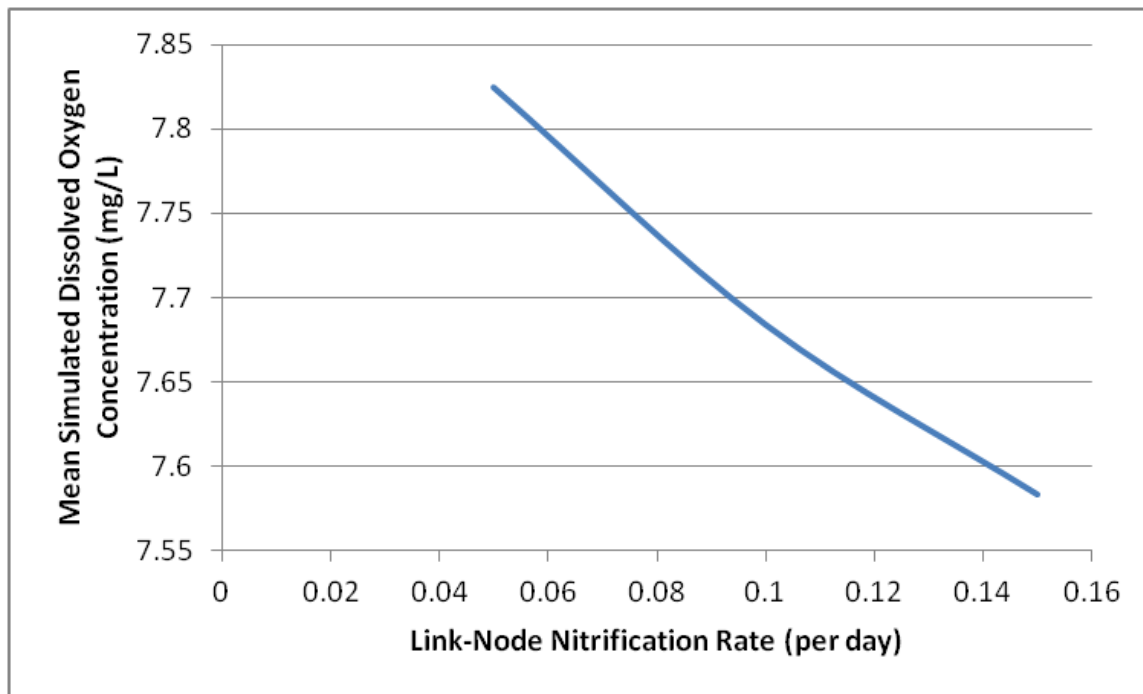
**Figure 20.** Link-Node dissolved oxygen relative and absolute error simulation statistics, calculated by month, Rough and Ready Island

### 3 Link-Node Dissolved Oxygen Simulation Sensitivity Analysis

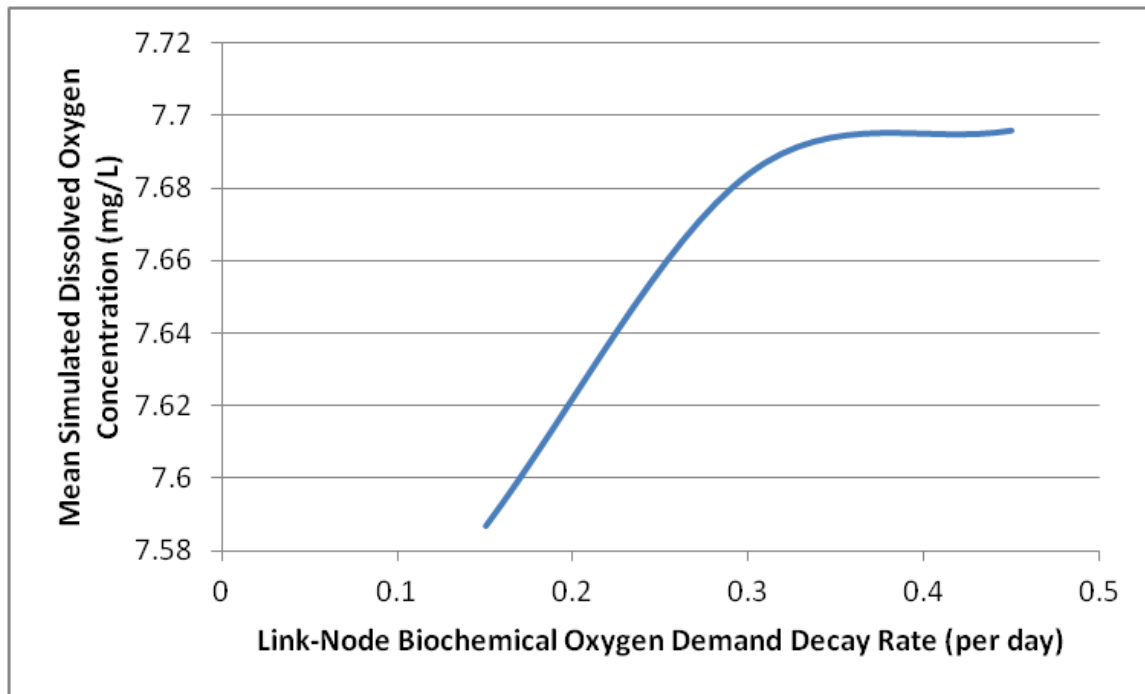
A variety of different simulations were run to investigate the sensitivity of simulated dissolved oxygen concentrations at Rough and Ready Island to changes in model input parameters. Figure 21 through Figure 24 illustrate the results of several of the sensitivity analyses that were performed. Figure 21 demonstrates that the net flow in the San Joaquin River does not have a substantial effect on dissolved oxygen concentration at Rough and Ready Island. An increase in discharge of 500 cfs (approximately 33% on average) results in an increase in mean simulated dissolved oxygen concentration at Rough and Ready Island of 1.3%. The Link-Node nitrification rate has a linear affect on dissolved oxygen concentrations (Figure 22). Increasing the nitrification rate from 0.05 to 0.15 results in a decrease in mean Rough and Ready Island dissolved oxygen concentration 0.242 mg/L (3% decrease). The effect of the BOD decay rate on dissolved oxygen concentration is not linear (Figure 23). Increasing the rate from 0.15 to 0.30 results in an increase in mean Rough and Ready Island dissolved oxygen concentration of 0.1 mg/L while increasing the rate from 0.30 to 0.45 results in a far smaller increase of 0.01 mg/L. The simulation results are not very sensitive to changes in the algae death rate (Figure 24), with a 300% increase in the death rate resulting in a less than one percent decrease in the Rough and Ready Island dissolved oxygen concentration.



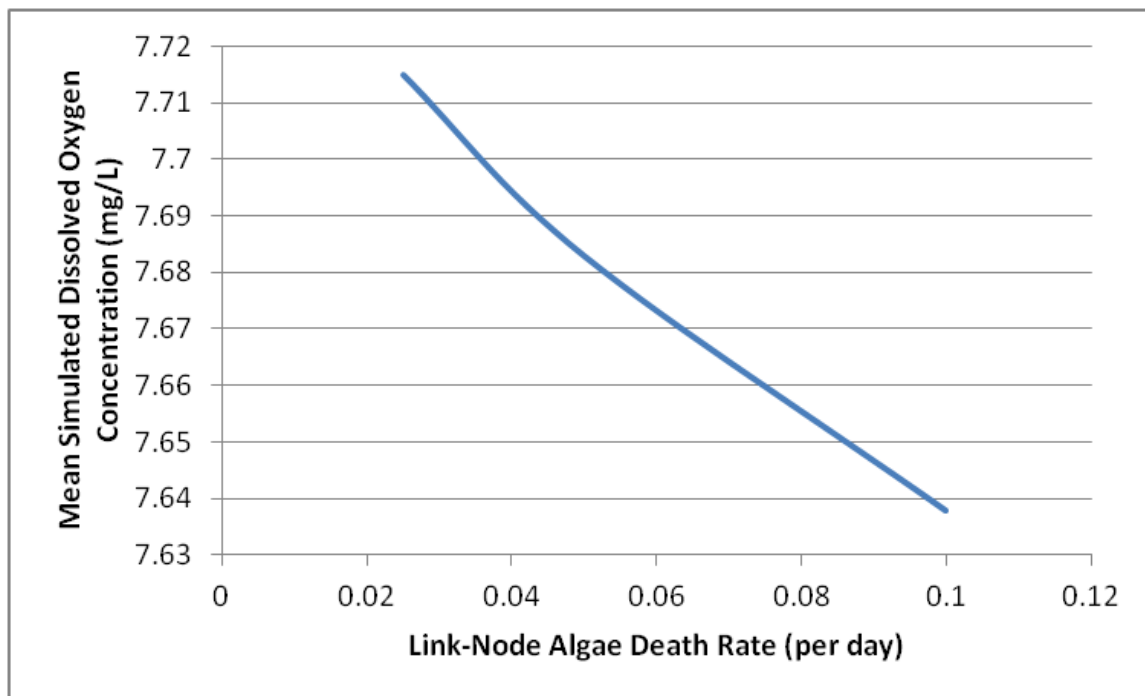
**Figure 21.** Link-Node dissolved oxygen simulation sensitivity to net San Joaquin River discharge



**Figure 22.** Link-Node dissolved oxygen simulation sensitivity to nitrification rate



**Figure 23.** Link-Node dissolved oxygen simulation sensitivity to biochemical oxygen demand decay rate



**Figure 24.** Link-Node dissolved oxygen simulation sensitivity to algae death rate

Figure 21 through Figure 24 provide examples of the sensitivity of the dissolved oxygen simulation to model input parameters. Many other parameters were tested, including channel

bathymetry, and aeration, phytoplankton growth and respiration, and detritus decay rates. Through these analyses, it was determined that the simulation of dissolved oxygen was sensitive enough to the aeration adjustment factor and the biochemical oxygen demand decay rate that these parameters could be used to calibrate the simulation to observed dissolved oxygen concentration data collected at Rough and Ready Island.

#### **4 Conclusion**

Systech Water Resources has invested significant effort in obtaining the best available information for the Link-Node input data sets, and calibrating the hydrodynamic and dissolved oxygen simulation to the Rough and Ready Island measured data. Based on the current calibration, Link-Node model is currently capable of simulating the hydrodynamics and dissolved oxygen concentrations in the San Joaquin River Deep Water Shipping Channel with precision and accuracy suitable for scenario analysis and TMDL development.

#### **5 Acknowledgements**

We gratefully acknowledge the Ecosystem Restoration Program and its implementing agencies (California Department of Fish and Wildlife, U.S. Fish and Wildlife Service, and the National Marine Fisheries Service) for supporting this project (E0883006, ERP-08D-SO3).

#### **6 Bibliography**

Chen, C W. "Concepts and Utilities of Ecologic Models." *Journal of Sanitary Engineering* 96, no. SA5 (1970): 1085-1907.

Chen, C W, and G T Orlob. "Ecologic simulation for aquatic environments." In *Systems analysis and simulation in ecology, volume III*, by B Patten, 475-588. Academic Press, 1975.

Chen, C W, and W Tsai. *Evaluation of alternatives to meet the dissolved oxygen objectives of the lower San Joaquin River*. San Ramon, CA: Systech Engineering, Inc., 1997.

Feigner, K D, and H S Harris. *Documentation report FWQA Dynamic Estuary Model*. Federal Water Quality Administration, 1970.

Schanz, R, and C W Chen. "City of Stockton Water Quality Model, Volume 1. Model Development and Calibration." PWA and Systech Engineering, Inc., 1993.